Conf. 790108--4

LA-UR -79-412

TITLE: PERFORMANCE SIMULATION AND PREDICTION

AUTHOR(S): J(ohn) Douglas Balcomb

SUBMITTED TO: Third National Passive Solar Conference
San Jose, California
January 12-13, 1979

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

PERFORMANCE SIMULATION AND PREDICTION*

by

J. Douglas Balcomb

Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

Computational procedures useful during the passive solar design process are discussed. Analysis tools are described suitable for each of the three phases of design: rules of thumb for the concept development phase, quick-and-dirty techniques for the design development phase, and the monthly solar load ratio method for the final design phase. Issues are discussed regarding the role of simulation analysis during the design process.

INTRODUCTION

Passive solar heating design analysis is conveniently separated into two phases--design development and final design. The building concept has presumably already been developed based on rules of thumb which are adequate for initial sizing of solar collection and heat storage elements. During the design development phase, the building design takes shape, becoming increasingly more defined during a series of iterations. Performance analysis is necessary during this phase to serve as a basis for more accurate sizing but the analysis must be short and simple, requiring not more than about fifteen minutes or it won't be usable to the designer. Some accuracy must be sacrificed for speed and convenience.

At the conclusion of design development, the design is tentatively approved and final design can begin. Final plans and specifications are drawn up. Final design analysis can be a part of this process, consisting of detailed heat load calculations, solar gain estimates, and solar heating predictions. This final process serves not so much to guide the design as to confirm the earlier estimates.

The importance of doing analysis during design development is emphasized by the progressive phasing of the process. This is when the passive solar and energy conservation aspects must be integrated into the design. If thermal analysis takes place only during final design, and then by a separate party, the results will not affect building geometry and construction materials which are so critical to effective passive solar. It poses an enormous challenge to develop design tools which are simple and fast and are also accurate and comprehensive.

This paper presents one approach, based on a correlation procedure. This procedure seems adequate for assessing solar gains and solar contribution to heating load. The problem of assessing the effectiveness of thermal mass is not as well developed and relies principally on sensitivity studies done with detailed computer simulations.

The role of simulation analysis as a design tool is not yet clear and is discussed at the end of the paper.

ANALYSIS FOR THE DESIGN DEVELOPMENT PHASE

Before any substantive solar analysis can begin, it is necessary to obtain an estimate of the building's thermal load. Normally, this is expressed as the number of Btu per hour required to maintain comfort on a design day and is used as a basis for sizing backup heating equipment. A number more commonly used in solar analysis is the heat loss coefficient, expressed n

*Work performed under the auspices of the U.S. Department of Energy, and funded by the Research and Development Branch for Solar Heating and Cooling, Office of the Assistant Secretary for Conservation and Solar Applications.

Btu/degree-day (Btu/DD). The design heating load and heat loss coefficient are closely related and one can easily be estimated from the other. The heat loss coefficient is normally in the range of 5 to 15 Btu/DD per square foot of floor area. It is the number of extra Btu's required per day which must be put into the building to maintain the temperature an additional one ^oF higher, for example, at 66^oF instead of 65^oF.

Quick-and-Dirty Estimate of Heat Loss Coefficient

A quick procedure for estimating the heat loss coefficient has been developed. Although not as accurate as a full-blown ASHRAE design load calculation, it is fast and is commensurate with the accuracy needed and the detail available during design development. It is based on some simple scaling laws, for example, that the building perimeter varies as the square root of the floor area.

The procedure consists of adding together several estimated contributions of heat loss.

Start with two inputs:

area = floor area of building

$$\text{number of stories} = \frac{\text{floor area of building}}{\text{floor area of ground floor}}$$

Then, either estimate the combined perimeter of all floors, or use:

$$\text{perimeter} = 4.24 \times \sqrt{\text{area}}$$

Then, either estimate the combined area of all east, west, and north windows, or use:

non-south window area = (perimeter) x (ceiling height) x (non-south window fraction)

where: non-south window fraction = .05, minimum window to .10, ample window.

Next, carefully estimate the south window area.

Then, compute the following:

Walls

$$L_w = 24 \times \frac{\begin{pmatrix}\text{peri-}\\\text{meter}\end{pmatrix} \times \begin{pmatrix}\text{ceiling}\\\text{height}\end{pmatrix} - \begin{pmatrix}\text{non-}\\\text{south}\\\text{window}\\\text{area}\end{pmatrix} - \begin{pmatrix}\text{south}\\\text{window}\\\text{area}\end{pmatrix}}{\text{R value of walls}}$$

Non-South Window

$$L_g = 26 \times \frac{(\text{non-south window area})}{\text{number of glazings}}$$

Perimeter (slab on grade)

$$L_p = 48 \times \frac{\text{perimeter}}{\begin{pmatrix}\text{number of}\\\text{stories}\end{pmatrix} \times \begin{pmatrix}\text{R value of}\\\text{perimeter} + 5\\\text{insulation}\end{pmatrix}}$$

Floor (over crawl space)

$$L_f = 24 \times \frac{(\text{area})}{\begin{pmatrix}\text{number of}\\\text{stories}\end{pmatrix} \times \begin{pmatrix}\text{R value}\\\text{of floor}\end{pmatrix}}$$

Note: normally only one of L_p or L_f will apply.

Roof

$$L_r = 24 \times \frac{(\text{area})}{(\text{number of stories}) \times (\text{R value of roof})}$$

Infiltration:

$$L_i = (0.432) \times (\text{average air changes per hour}) \times (\text{ceiling height}) \times (\text{area})$$

Note: The coefficient 0.432 applies at sea level. At higher elevations, subtract 0.013 from 0.432 for each 1000 ft., for example, use 0.302 at 10,000 ft. elevation.

South Facing Glass

$$L_s = (24) \times (\text{Glazing Area}) \times (\text{Average U-value})$$

Note: If night insulation is used the U-value should be the time average of the insulated and non-insulated values.

Add the appropriate components to obtain the final estimate, for example:

$$L = L_w + L_g + L_r + L_p + L_i + L_s$$

Estimating Average Temperature in Direct Gain Buildings

For direct gain passive solar buildings it is good design practice to size solar collection glazing to raise the 24-hour average temperature into the comfort range on a clear January day. If more glazing than this is used then the building will surely overheat on clear days. The total clear-day ΔT is given by:

$$\Delta T = \frac{\text{total clear-day daily heat gain}}{\text{heat loss coefficient}}$$

where the total daily clear-day heat gain is the combined total due to solar gains and any internal heat sources within the building. The input due to solar gains can be estimated from the ASHRAE clear-day tables which give solar radiation through single glazing for different orientations and different tilts.[1] The following table lists transmission through double glazing for south facing vertical and 60° tilts.

CLEAR-DAY SOLAR GAINS

Btu/day - sq.ft.

Latitude	Vertical	60° Tilt
32	1466	1738
36	1457	1663
40	1416	1560
44	1335	1424
48	1207	1249

Note: These values account for reflection losses and one-half of the absorption losses (assuming absorption in the inner glazing remains in the building.) Adapted from unpublished tables by Steven Baker.

The input due to internal generation (due to lights, people, appliances, etc.) is quite variable but for residential applications is normally about 20000 Btu/day per person living in the house.

The procedure is to estimate the clear day ΔT using the formula given above and add this value to the average January temperature, as tabulated, for example, in Ref. 2. If this sum lies in the 70's then the glazing is adequately sized. If a higher solar fraction is desired then the glazing might be increased, but not by more than 10 to 15%, understanding that some overheating will occur on clear days.[3]

Estimating Solar Contribution

Techniques for estimating solar contribution are based on correlations derived from many hour-by-hour computer simulations. The procedure is very simple and fast to use, consisting of two steps.

Step 1. Compute the Load Collector Ratio (LCR), in Btu/DD-ft^2, as follows:

$$\mathrm{LCR} = \frac{\text{heat loss coefficient} \begin{pmatrix}\text{Exclusive of}\\ \text{south glazing}\end{pmatrix}}{\text{solar collection area}}$$

Note that the heat loss coefficient should be without the south glazing. Simply subtract L_s from the total.

Step 2. Look up the solar heating fraction estimate from tables given in Ref. 4 (for Trombe walls and water walls) or Ref. 5 (for direct gain). For mixed systems, average the results.

Note that the tables in Refs. 4 and 5 are for reference designs having adequate heat storage, and apply to designs with south-facing double glazing with a thermostat setting of 65° without the effect of internal heat generation. This is roughly equivalent to a thermostat setting of 70°F if one were to take into account normal internal heat generation associated with residential situations.

Estimating the Effect of Variations in Design Parameters

The effect of changing a design parameter (other than the area of glazing) can be assessed by studying the published results of hour-by-hour calculations in which the various parameters are varied one at a time. These are given in Refs. 6 and 7 for several storage wall designs and in Ref. 8 for direct gain situations.

ANALYSIS FOR THE FINAL DESIGN PHASE

Once the initial design has been completed a more comprehensive final design can be undertaken. The monthly solar load ratio method is a technique developed at Los Alamos which enables the designer to obtain performance estimates based only on building heat loss coefficient and monthly values of solar radiation and heating degree days.[4,5] There may be other reasons to use this method instead of the LCR tables described earlier, for example:

- The location is not listed in the tables.
- The collection surface is not due south or not vertical.
- It is desired to predict the month-by-month character of the solar heating.

Heat Loss Coefficient

If a comprehensive ASHRAE heating load analysis has been done on the building (a fairly large job in itself), then the heat loss coefficient is easily estimated as follows:

$$\begin{matrix}\text{Heat}\\ \text{Loss}\\ \text{Coefficient}\end{matrix} = \frac{24 \times (\text{Design Heating Load})}{\begin{pmatrix}\text{Inside}\\ \text{Temperature}\end{pmatrix} - \begin{pmatrix}\text{Design}\\ \text{Temperature}\end{pmatrix}}$$

where: Design Heating Load = Calculated heat required (Btu/hr) to maintain the building at a fixed inside temperature if the outside temperature is equal to the design temperature, in the absence of solar gains or internal heat.

Alternatively (and less accurately), the previously described quick-and-dirty technique can be used to estimate heat loss coefficient.

Solar Load Ratio

The solar load ratio (SLR), is defined as follows:

$$\mathrm{SLR} = \frac{\text{monthly solar radiation absorbed}}{\text{monthly building load}}$$

The numerator is obtained by estimating the solar radiation transmitted through the glazing and multiplying by the solar absorptance of the space behind the glazing. The difficult part is to translate the solar radiation data, which are usually measured and tabulated for a horizontal surface, to the plane of interest which is usually at a quite different orientation. A simple correlation has been derived and published in Ref. 4, which applies to a vertical, south-facing surface with double glazing and a ground reflectance of 0.3. This problem is not unique to passive applications and has been addressed by Klein[9] and Utzinger,[10] among others.

For the denominator of the SLR, the following can be used:

$$\begin{pmatrix}\text{monthly}\\ \text{thermal}\\ \text{load}\end{pmatrix} = \begin{pmatrix}\text{heat}\\ \text{loss}\\ \text{coefficient}\end{pmatrix} \times \begin{pmatrix}\text{monthly}\\ \text{heating}\\ \text{degree-days}\end{pmatrix} + C65$$

where C65 is a correction for the 65°F base and can be estimated as follows:

$$C65 = 30 \times \left[(T_{st} - 65) \times \begin{matrix}\text{heat}\\ \text{loss}\\ \text{coefficient}\end{matrix} - \begin{matrix}\text{daily}\\ \text{internal}\\ \text{heat}\\ \text{generation}\end{matrix} \right]$$

This provides a means of estimating the effects of a particular thermostat setting, T_{st}, and internal heat generation.

The designer should be conservative in estimating the amount of internal heat generation, particularly if it represents a large fraction of the total heat load, because it will not all be useful in offsetting the load due to differences in timing.

Solar Savings

The final step consists of estimating the solar savings based on a correlation of the solar heating fraction (SHF) as a function of the SLR. Although the monthly SHF may vary statistically for the same value of SLR (as much as ±8% for monthly SHF's in the range of 70-90%), the recommended procedure is to estimate based on averages. Month-to-month variations will tend to average each other out and the SLR will provide a good estimate of the long-term average.

The correlation curves have been developed based on many hour-by-hour simulations for several loads and many climates. Exponential functions have been used for the correlations as follows:

$$SHF = a_1 \times SLR \qquad , SLR \leq R$$

$$SHF = a_2 - a_3 \times e^{-a_4 \times SLR} \qquad , SLR > R$$

$$(SHF \leq 1)$$

where the values of a_1, a_2, a_3, a_4, and R which lead to least-square errors in annual solar fraction are as follows:

TABLE I

Passive Feature	Night Insulation	R	a_1	a_2	a_3	a_4
Direct Gain	No	0.1	0.618	1.010	1.071	1.221
Direct Gain	Yes	0.6	0.887	1.003	1.265	1.647
Trombe Wall	No	0.1	0.452	1.014	1.039	0.705
Trombe Wall	Yes	0.5	0.720	1.007	1.120	1.095
Water Wall	No	0.8	0.600	1.015	1.260	1.070
Water Wall	Yes	0.7	0.764	1.010	1.403	1.546

The procedure is to calculate the solar gains, thermal loads, SLR's, and corresponding SHF's all on a monthly basis. The monthly solar savings is:

$$\text{Solar Savings} = \text{Monthly Thermal Load} \times \text{Monthly SHF}$$

and the annual solar savings is computed as the sum of the monthly values.

This procedure has been used as a "common basis" solar analysis during the HUD Passive Solar Design Competition[11] and has proven to be an effective tool for comparative evaluation. Time will tell whether it provides an acceptable benchmark for realistic performance estimation.

MIXED SYSTEMS

Most passive designs consist of a mixture of the basic approaches. Few Trombe walls are without some direct gain component. Most water walls are spread-apart tubes or other containers which allow some direct heating. There has been some confusion as to how to deal with these combinations by the SLR method.

The recommended procedure is to compute a single SLR, based on the total solar gain through all glazing divided by the total net thermal load, and then compute a weighted-average SHF. This is determined by computing a separate SHF for each design approach and averaging between them based on the relative proportion of each glazed area.

THE ROLE OF SIMULATION ANALYSIS

Simulation analysis consists of representing the physical system by a set of mathematical equations which account for the flow of heat between various locations within the system and the storage of heat energy by various massive elements. Passive systems have proven to be quite accurately represented by relatively straightforward and simple simulations. Numerical differencing techniques are commonly employed to solve the equations conveniently using one-hour time steps in the solution. Temperature histories in test rooms and other passive solar structures have been shown to be very predictable, using relatively few equations to describe the physical heat flow processes. Expanding the complexity of the analysis and the number of equations is generally warranted only to describe more complex situations, such as multi-room geometries, or to obtain insight into the details of temperature distributions within a space.

The techniques which have been described in the first part of this paper are based on multiple year-long simulation analyses done for a variety of climates.

Given the success of these techniques, the question then becomes: Should simulation analysis itself be used as a design tool? There are several options open, each of which has been used to some extent. Research groups and others with access to large computer facilities have used them in the process of designing a few buildings. While suitable for this purpose, this practice could hardly be expected to survive in the design marketplace. It is too expensive in terms of both analysis talent and computer time. At the other end of the scale several simple simulation techniques have been programmed for hand-held programmable calculators. These are quite limited in terms of their ability to handle either complex situations or extended time periods. Not only is the computing time extended but the weather and solar data must be fed in manually as the simulation progresses. Although making very economical use of equipment, the process is laborious and expensive in terms of personnel time. It is also impractical to attempt year-long simulations to overall energy savings or even to simulate a comprehensive variety of weather patterns.

Between these two options are time sharing computer systems and desk top microcomputers. Time sharing systems require a moderately expensive terminal and involve charges for telephone lines and computer time. The advantage is that powerful codes and extensive weather files can be accessed.

The advent of inexpensive desk top minicomputers presents another intriguing option. These are very powerful (compared to a hand-held calculator) and easily capable of a very respectable simulation analysis. Computation time will be moderately long, compared to a large computer, but quite acceptable to an operator studying one- or two-week weather periods. Year-long simulations may take a matter of two or more hours but can be left unattended and perhaps only done once per building design as a part of the final design analysis. A host of solar geometry and other fast routines can be packaged to provide quick information access useful during design development. The whole process can be made simple, interactive, and fun.

The input and output of information from a minicomputer is a problem. Good equipment, such as disks and printers, is expensive. The graphics capabilities of the CRT displays are very limited. Tape recorders are very slow. However, there are many options available and prices are expected to come down markedly even as capability increases.

The key question is the following: Will a normal design office, such as an architectural or building engineering firm be able and willing to support both the cost of equipment and specialized personnel to do this type of analysis? The probable answer is—yes, ultimately. It will be a slow process of assimilation and learning.

The power of the simulation technique is so great and so compelling that it will ultimately be the preferred approach. Correlation techniques cannot be expected to cope adequately with the variety of weather conditions and design approaches that can be encountered. For standard situations, however, they are suitable and will certainly continue to provide needed and useful analysis tools.

REFERENCES

1. ASHRAE Handbook of Fundamentals, 1977, Chapter 26.

2. U.S. Department of Housing and Urban Development, "Intermediate Minimum Property Standards Supplement, Solar Heating and Domestic Hot Water Systems, GPO, Order No. 4930-Z, $12.00. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Published 1977.

3. E. Mazria, "The Passive Solar Energy Book," Rodale Press, Organic Park, Emmons, PA. 18049, 1979.

4. J. D. Balcomb, and R. D. McFarland, "A Simple Empirical Method for Estimating the Performance of Passive Solar Heating Systems," Proceedings of the 2nd National Passive Solar Conference, Philadelphia, March 1978. Also Los Alamos report LA-UR-78-1159 (1978).

5. W. R. Wray, J. D. Balcomb, and R. D. McFarland, "A Semi-Empirical Method for Estimating the Performance of Direct Gain Passive Solar Heated Buildings," Proceedings of the 3rd National Passive Solar Conference, San Jose, CA, January 1979.

6. J. D. Balcomb, J. C. Hedstrom, and R. D. McFarland, "Passive Solar Heating of Buildings," Los Alamos report LA-UR-77-1162 (1977), and Sandia Laboratories report SAND 77-1204 (1977).

7. J. D. Balcomb and R. D. McFarland, "The Effect of Design Parameter Changes on the Performance of Thermal Storage Wall Passive Systems," Proceedings of the 3rd National Passive Solar Conference, San Jose, CA, January 1979.

8. W. R. Wray and J. D. Balcomb, "Sensitivity of Direct Gain Space Heating Performance to Fundamental Parameter Variations," submitted to Solar Energy. Also Los Alamos report LA-UR-78-2570.

9. S. A. Klein, "Calculation of Monthly Average Insolation on Tilted Surfaces." Proceedings of the American Section International Solar Energy Society, Winnepeg, Manitoba, Canada, August 1976, Vol. 1, page 376.

10. D. M. Utzinger, "A Method of Estimating Monthly Average Solar Radiation on Shaded Surfaces," Proceedings of the 3rd National Passive Solar Conference, San Jose, CA, January 1979.

11. U.S. Department of Housing and Urban Development, "Passive Residential Design Competition and Demonstration, H 8600," August 1978.